

LONG DURATION EXPOSURE FACILITY (LDEF)
OPTICAL SYSTEMS SIG SUMMARY AND DATABASE

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INTRODUCTION

The main objectives of the LDEF Optical Systems Special Investigative Group (SIG) discipline are to develop a database of experimental findings on LDEF optical systems and elements hardware, and provide an optical system overview. Unlike the Electrical and Mechanical disciplines, the Optics effort relies primarily on the testing of hardware at the various principal investigator's laboratories, since minimal testing of optical hardware was done at Boeing. This is because all space-exposed optics hardware are part of other individual experiments.

At this time, all optical systems and elements testing by experiment investigator teams is not complete, and in some cases has hardly begun. Most experiment results to date, document observations and measurements that "show what happened". Still to come from many principal investigators is a critical analysis to explain "why it happened" and future design implications.

This paper summarizes the original optical system related concerns, the lessons learned at a preliminary stage in the Optical Systems Investigations and describes the design of the Optical Experiments Database. Finally, this paper describes how to acquire and use the database to review the LDEF results in detail.

OPTICAL SYSTEMS RELATED CONCERNS

From a system's point of view, the degradation of an individual optical element can easily affect the overall system performance. For instance, surface degradation of a space-exposed transparent optical element, may cause an increase in diffuse scatter with a resulting loss of light transmission. In terms of the optical system, this could significantly degrade the final image resolution. The following outline identifies some of the original optical systems-related concerns:

- Degradation of transparent elements (darkening, contamination, impacts)
 - reduce the throughput of available light for radiometric, photometric, and imaging systems
 - degrade image resolution
- Degradation of optical coatings (erosion, discoloration, delamination, pitting, contamination)
 - holes in coating may alter wavelength dependent transmission and reflection properties of the coating
 - degraded or damaged coating may encourage initiation of other types of damage
 - redeposition of contaminants (including damaged coating material) on other system optics may cause loss of resolution, reduced throughput or altered wavelength dependence
- Degradation of diffuse paints or diffuse metal coatings in optical systems (erosion, discoloration)
 - baffling efficiency may decrease due to increase in specular reflection, or may increase due to an increase in roughness of baffle surface topography
 - redeposition on other materials
 - contamination of system optics (loss of resolution, reduced throughput, altered wavelength dependence)
- Degradation of fiber optics (radiation darkening, impacts, contamination)
 - reduced transmission
 - complete loss of signal
 - increase in system bit error rate (digital)

- decrease in signal-to-noise ratio (analog)
- Detector changes
- responsivity
 - detectivity
 - rise time (system bandwidth)

LDEF OPTICAL MATERIALS "LESSONS LEARNED" SUMMARY

The LDEF optical hardware samples can be divided into seven groups for summarizing the general "lessons learned" up to the time of this report. Those groups are uncoated optical materials, coated optical materials, solar cells, fiber optics, detectors, reflectometers and radiometers, and optical sources. The results summaries are described in the following paragraphs.

Uncoated Optical Materials

Five LDEF experiments containing uncoated optical materials were reviewed. In general, hard uncoated optical materials were found to be quite resistant to the space environment. Even micrometeoroid/debris (M/D) impacts tended to have only localized damage without significant degradation of the optical performance. The impact sites appeared as craters surrounded by an expanded area of damage caused by melting, cratering, spallation or small fracture patterns.^{1 2} On samples exhibiting contamination, the spectral transmission could vary from no detectable change to catastrophic loss in transmission.^{3 4} This emphasizes the need for contamination prevention throughout any future mission duration. Exposed soft uncoated optical materials like thallium bromide (KRS-5 and KRS-6) experienced gross physical degradation of the substrate material as a result of excess space exposure, especially the effects of atomic oxygen bombardment.⁵

Coated Optical Materials

Several important observations were described on the LDEF experiments coated optical materials after their exposure to low earth orbit environments. Specifically, copper and silver coated optics showed oxidation due to atomic oxygen bombardment.⁶ Thermal cycling or thermal excursions were implicated in the delamination of dielectric and metallic coated optics.⁷ Contamination was shown to degrade transmission in many coated optical materials; however when the contaminant was cleaned, transmission results often returned to pre-flight measurements.⁸ Some evidence of environmental degradation in the fluoride compound protective or antireflection coatings (e.g. MgF₂, CaF₂) was noted.⁹ As with the uncoated optical materials, the micrometeoroid and debris (M/D) impacts showed localized impact damage effects, but their actual damage potential was often dependent on the impact density on the coated optical material.¹⁰

Note that some causes of anomalies on the LDEF coated optical materials have not yet been determined. Further, other non-environmental sources of material degradation (e.g. sample shelf life, sample handling, manufacturing defects) must be reassessed prior to making final conclusions about the extent of low Earth orbit (LEO) space exposure on LDEF coated optical materials.

Solar Cells

Solar cell components flew on three LDEF experiments reviewed. In general, solar cell experiments revealed a variety of effects from the space exposure including: micrometeoroid impacts (from small nicks in cover glass to penetration of the cell), broken interconnects, silver oxidation or loss, scattered contamination, and a loss of fluorine in the antireflection coatings.^{11 12 13} Some power degradation was also noted which was dependent on the severity of the M/D impacts.¹⁴ A great deal of information is still forthcoming from the principal investigators on optical properties of the surfaces of the cells, electrical characteristics, semiconductor properties, and radiation damage assessment.

Fiber Optics

Three experiments flew fiber optics, and a fourth experiment evaluated fiber optic connectors. Overall, fiber optics performed well in the low earth orbit space environments during the LDEF mission, with little or no degradation to the optical performance.^{15 16 17} Environmental effects were generally confined to the protective sheathing, suggesting fiber optic systems can be successfully used in low earth orbit. However, if struck with a direct hit by a micrometeoroid impact or debris that reaches the optical fibers, as was observed on only one link during the 2115 days in orbit, then catastrophic damage can result.¹⁸ Further studies into contamination protection schemes and temperature effects on optical performance were also suggested.¹⁹

For instance, post-flight experiments performed on space exposed fibers in the S0109 experiment showed an increase in transmission loss with decreasing temperature, becoming much steeper near the lower end of their temperature range. This was observed in most (but not all) fiber cables in experiment S0109. The largest change was seen in the C-6 sample, which had an attenuation increase about 3.5 dB at the low temperature extreme. The principal investigator for this experiment, describes this behavior as due to the specific cable structure (rather than the fiber), and would preclude its use in a severe space environment.²⁰

Contamination was recorded on internal and external surfaces on two experiments.^{21 22} Experiment results suggest only a slight degradation to nominal optical performance due to contaminants. Since contaminating films or particles over the optically important core would contribute to degradation in optical performance, recommendations were made to mate or cover connectors in a manner that protects the core from contamination.

Finally, experimenters discussed the expectation that using today's improved radiation hard fiber optic cable would enable space missions to experience longer runs and higher doses of radiation. The data from these LDEF experiments, provides for improved radiation exposure data and performance predictions for future use of fiber optics in space.^{23 24}

Detectors

Four LDEF experiments contained detectors to test their resistance to space environmental exposure. Most detectors were not degraded by the space exposure. One notable exception was the tryglycine sulfide pyroelectric detector which had a 100% detectivity failure rate on both the control and flight samples.²⁵ This was in contrast to the lithium tantalate and strontium-barium-niobate pyroelectric detectors which suffered no measureable loss of performance.²⁶ The other detectors on the LDEF included HgCdTe detectors, InGaAs photodiodes, large area silicon photodiodes and PIN diodes. These detectors had good performance and no apparent degradation effects.^{27 28 29 30}

In addition to the sensor elements, one LDEF experiment underlined the importance of the choice of lens or window for the detector. Since the detector is located behind the window, a damaged window can contribute significantly to the degradation of the entire detector system optical performance. For instance on this experiment, the thallium bromide windows (KRS-5) failed, while the germanium windows did not.³¹

Reflectometers and Radiometers

Certain LDEF experiments described the performance of radiometers and reflectometers for the measurement of solar and thermal properties. In general, all of the measuring instruments met their performance criteria, and provided valuable data on incident radiation.^{32 33 34}

Optical Sources

Several kinds of optical sources flew on LDEF including solid and gas lasers, flashlamps, standard lamps, and light-emitting-diodes (LED's). Of the laser optical sources, the semiconductor laser diodes and light-emitting-diodes (LED's) were not degraded by the space environment.^{35 36} However, no lasing action could be obtained from the gas lasers, which was thought to be due to changes as a result of gas diffusion through the glass envelope.³⁷

The deuterium ultraviolet (UV) lamp and tungsten filament quartz envelope lamp, which were part of a reflectometer subsystem, showed nominal power and computer-control post-flight functional test results. However, the deuterium lamp irradiance appeared slightly unstable (flickering of the light arc); while the tungsten lamp irradiated normally.³⁸ Other optical sources are still under investigation.

OPTICAL EXPERIMENTS DATABASE

One of the main objectives of the LDEF Systems SIG Optics discipline is to develop a database that identifies the optical hardware flown, summarize experimental results and conclusions, and provide future design considerations. Compiling this information into an easily accessible database format, and making it available to the space community, is a major task accomplished by the System SIG Optics effort.

After a trade study of Boeing standard software packages, Filemaker Pro was chosen as the Optical Experiments Database software application program. Filemaker Pro is a database manager for the Macintosh computer produced by Claris Corp.³⁹ It is a flat, text-retrievable database that provides access to the data via an intuitive user interface without tedious programming. Though this software is available only for the Macintosh computer at this time, copies of the database can be saved to a format that is readable on a personal computer as well. "Relational" databases were examined for this application, but found to have many features and capabilities unnecessary for this application.

Within the Filemaker Pro application, the LDEF Optical Systems information is placed in a file called "LDEF_data". Within that file, each individual LDEF experiments has its own "record". Each record contains specific information using "field name" headings, from which one can view or print reports from the provided layout. The database was designed to 1) be user friendly, 2) ensure data traceability, 3) acknowledge authors, 4) be upgradeable, and 5) have access privileges that allow full viewing but not editing.

The database will be available to the space community for review by contacting the LDEF Project office for information. Along with a disc copy of the database, you will receive an LDEF User's Manual which will detail the following steps:

1. Computer start-up and database password access
2. Working with information
 - a. finding information
 - b. browsing records
 - c. moving from record to record
 - d. sorting information
3. Previewing and Printing
4. Exchanging Information
5. Help function
6. Quitting Filemaker Pro

CONCLUSIONS

The Optical Systems SIG have provided to NASA an Optical Systems Overview and an LDEF Optical Experiments Database, which were summarized in this paper. Further details of this investigation can be found in the LDEF Systems Special Investigation Group Final Report, Boeing Defense and Space Group, NASA contract NAS1-19247 Task 1, January 1992. The support of NASA Langley Research Center through the LDEF Project Office is gratefully acknowledged in this effort.

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